Land use/land cover change responses to ecological water conveyance in the lower reaches of Tarim River, China

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Abstract: The Tarim River is the longest inland river in China and is considered as an important river to protect the oasis economy and environment of the Tarim Basin. However, excessive exploitation and over-utilization of natural resources, particularly water resources, have triggered a series of ecological and environmental problems, such as the reduction in the volume of water in the main river, deterioration of water quality, drying up of downstream rivers, degradation of vegetation, and land desertification. In this study, the land use/land cover change (LUCC) responses to ecological water conveyance in the lower reaches of the Tarim River were investigated using ENVI (Environment for Visualizing Images) and GIS (Geographic Information System) data analysis software for the period of 1990–2018. Multi-temporal remote sensing images and ecological water conveyance data from 1990 to 2018 were used. The results indicate that LUCC covered an area of 2644.34 km^2 during this period, accounting for 15.79% of the total study area. From 1990 to 2018, wetland, farmland, forestland, and artificial surfaces increased by 533.42 km^2 (216.77%), 446.68 km^2 (123.66%), 284.55 km^2 (5.67%), and 57.51 km^2 (217.96%), respectively, whereas areas covered by grassland and other land use/land cover types, such as Gobi, bare soil, and deserts, decreased by 103.34 km^2 (14.31%) and 1218.83 km^2 (11.75%), respectively. Vegetation area decreased first and then increased, with the order of 2010<2000<1990<2018. LUCC in the overflow and stagnant areas in the lower reaches of the Tarim River was mainly characterized by fragmentation, irregularity, and complexity. By analyzing the LUCC responses to 19 rounds of ecological water conveyance in the lower reaches of the Tarim River from 2000 to the end of 2018, we proposed guidelines for the rational development and utilization of water and soil resources and formulation of strategies for the sustainable development of the lower reaches of the Tarim River. This study provides scientific guidance for optimal scheduling of water resources in the region.

Keywords: land use/land cover change (LUCC); remote sensing; land use dynamic index; ecological water conveyance; Tarim River

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1 Introduction

The Tarim River, located in Xinjiang Uygur Autonomous Region, is the longest inland river in China and has the dual characteristics of rich natural resources and fragile ecosystems. The region around this river is favorable for the construction of the "Silk Road Economic Belt", which will aid in the economic and social development of China (Chen et al., 2020; Zuo et al., 2021). The river basin is characterized by an extremely arid environment, and most of the natural processes and human activities in the basin are directly or indirectly affected by water shortages (Deng et al., 2017; Chen et al., 2020). The lower reaches of the Tarim River have become one of the focuses for ecological and environmental research in Northwest China, and the issues of ecological restoration and security have attracted significant attention from the society and government (Yu et al., 2016; Keram et al., 2019; Zhou et al., 2020).

To restore and protect the downstream ecology, the Chinese government implemented a comprehensive management system for the Tarim River Basin in the year 2000 (Chen et al., 2004; Ablekim et al., 2016). The development of intermittent ecological water conveyance project has altered the ecology and environment of the basin, resulting in land use/land cover change (LUCC) (Bao et al., 2017; Wang et al., 2021).

Numerous studies have investigated the vegetation, biomass, groundwater, LUCC, and ecological benefit assessment responses of ecological water in the lower reaches of the Tarim River (e.g., Shi et al., 2010; Liu et al., 2014; Bao et al., 2017; Chen et al., 2020). For example, Deng et al. (2016) analyzed and evaluated the ecological response benefits of vegetation physiology and vegetation restoration after ecological water conveyance by monitoring surface water, groundwater, soil water, and vegetation samples based on a local investigation of the ecological environment in this region. Chen et al. (2004) analyzed the ecological effect of ecological water conveyance in this region by studying the vegetation land of the ecological section. Changes in the fractional vegetation coverage (FVC) in the lower reaches of the Tarim River have been monitored from 2000 to 2017, using the time sequence normalized difference vegetation index (NDVI) data produced by MOD13Q1; further, the growth and recovery of vegetation in the region under ecological water conveyance have also been explored (Zhu et al., 2019). By combining Landsat TM/ETM and China & Brazil Earth Resource Satellite/Charge-coupled Device (CBERS/CCD) remote sensing images, Liu et al. (2014) studied vegetation restoration for the period of 1999–2010 in this area based on soil-adjusted vegetation indices.

LUCC is an important factor in measuring the sustainable development of the ecology in a region. Therefore, it is important to study LUCC to effectively understand the environmental changes and sustainable development (Hao and Ren, 2009; Schirpke et al., 2012). However, there are few studies that use multi-source remote sensing and long-time series data to monitor and analyze regional environmental changes and ecological responses.

The ecological water conveyance project in the lower reaches of the Tarim River has lasted nearly 20 a. This study monitored and analyzed the LUCC of the regional environment and ecological responses based on multi-temporal remotely sensed images obtained between 1990 and 2018 (over 29 a) in the lower reaches of the Tarim River. Specifically, we used ENVI (Environment for Visualizing Images) and GIS (Geographic Information System) and statistical data analysis software to analyze the spatial distribution and temporal dynamics of LUCC, as well as the responses of land use change, trend, and spatial characteristics under intermittent water conveyance conditions.

2 Study area

The lower reaches of the Tarim River, located in South Xinjiang of China, mainly refer to the section from the Daxihaizi Reservoir to the Taitema Lake, with a total length of approximately 428 km (Sun et al., 2011). Riparian forests are formed in the arid area of the lower reaches of the Tarim River, forming a "green corridor" in the desert, which blocks the connection between the Taklamakan Desert and and Kuruktag Desert (Zhou et al., 2020; Zhang et al., 2021). Affected by

the climate of the two deserts, the lower reaches of the Tarim River experience drought with less rainfall and snowfall, strong evaporation, and high gale frequency in spring and autumn. The region is characterized by a typical northern temperate continental arid desert climate, with annual average temperature between 10.7°C and 11.5°C, precipitation between 17.4 and 42.0 mm, and evaporation up to 2500–3000 mm (Xu et al., 2019; Li et al., 2021). The ecological environment in the region is extremely sensitive and fragile.

Since the year 2001, the local government has launched the ecological water conveyance project for the Tarim River Basin. Unified water scheduling was implemented in the entire river basin, and emergency ecological water transport project was carried out for downstream ecological rescue, restoration, and protection (Ablekim et al., 2016; Chen et al., 2019). From 2000 to the end of 2018, a total of 19 ecological water transfers (27 phases) were carried out, with a total water delivery volume of 707.0×10^8 m^3 (Fig. 1), resulting in the water reached the Taitema Lake for more than 16 times.

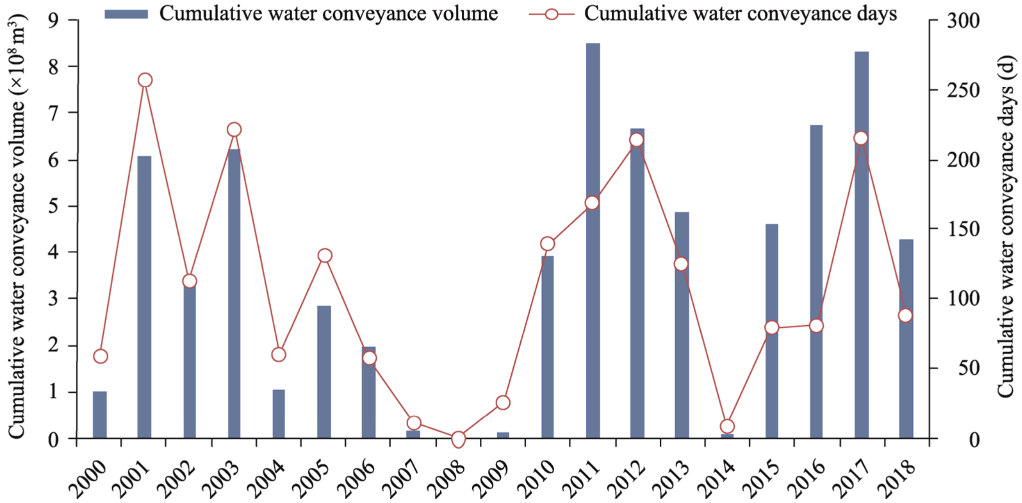

Fig. 1 Annual variations of cumulative water conveyance volume and cumulative water conveyance days in the lower reaches of the Tarim River from 2000 to 2018

The geographical location of the study area falls within 39°00′–41°30′N and 86°00′–89°30′E (Fig. 2). The Taitema Lake is the lowest point in the region, at 801.50 m. To investigate all the areas that have been affected by the ecological water conveyance, we considered the main ecological water conveyance channel as the central line, and established buffer zones of 30–50 km on both sides. This study focused on the region between the buffer zones on both sides of the river.

3 Materials and methods

3.1 Data acquisition

Landsat TM, ETM, and OLI images in 1990, 2000, 2010, and the summer and autumn of 2018 were used in this study. These images included multi-scene remote sensing data with track numbers 143/31, 142/31, 142/32, 142/33, 141/31, 141/32, 141/33, 141/34, and 140/33. We geometrically corrected the images of 2000, 2010, and 2018 using an image-to-image registration method based on the 1990 images. After geometric correction, the image data were inlaid with nine sets of remote sensing images. We selected a scene image with the largest area and good data quality as the reference image and balanced other images according to it. The FLAASH module in ENVI 5.3 software was used for atmospheric correction of the images to eliminate atmospheric effects.

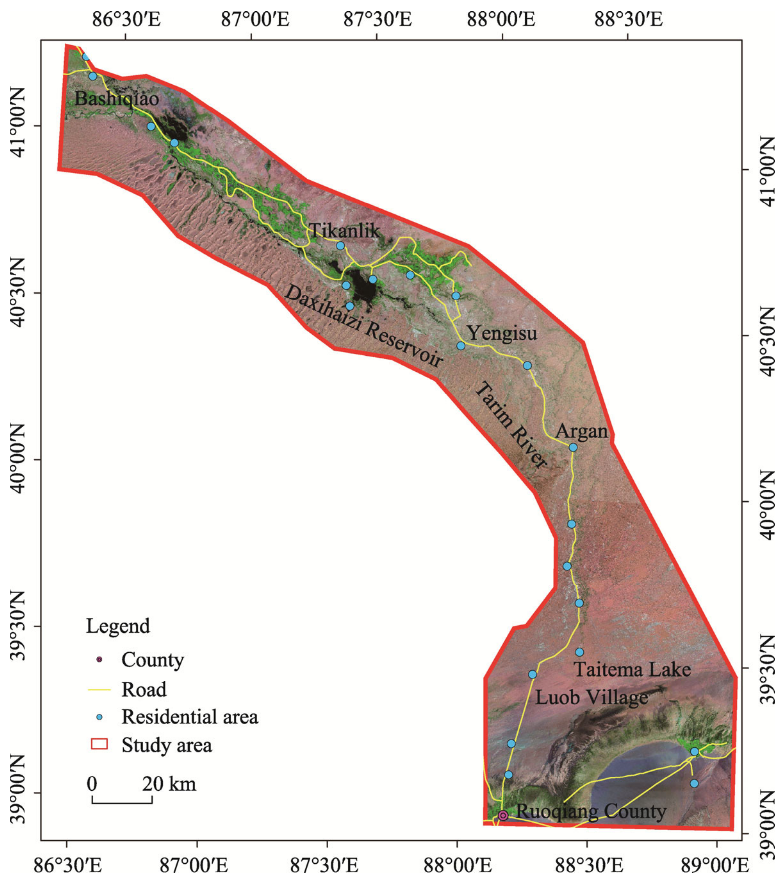

Fig. 2 Overview of the lower reaches of the Tarim River

3.2 Random forest algorithm

The random forest (RF) algorithm is an ensemble learning method used for data classification and regression, among other tasks (Breiman, 2001). Compared with other methods, the RF algorithm performs well with less training sample sets and shorter computation time, and provides more accurate results through its out-of-bag error estimation (Demarchi et al., 2014). Hence, the RF algorithm has proved to be a highly robust discrimination method when remotely sensed spectra represent combinations of a variety of materials. The RF algorithm was run using the image RF toolbox of EnMAP-Box v1.3. Figure 3 shows the flowchart of the methods involved from imaging to the results, including the pre-processing.

Based on the characteristics of land use/land cover and planning in the lower reaches of the Tarim River (He et al., 2010), we classified the land use/land cover units as Level-1 of the China land resource classification system, which includes meadowland, forestland, wetland, farmland, artificial surfaces, and other land use/land cover types, such as Gobi, bare soil, deserts, and so on (Fig. 4). The overall classification accuracies were 82.27%, 85.92%, 83.21%, and 87.21%, for 1990, 2000, 2010, and 2018, respectively, which meet the demand for land use/land cover monitoring.

3.3 Land use dynamic indices

3.3.1 Single land use dynamic index ($P1$)

The single land use dynamic index ($P1$; %) indicates the quantitative changes in a particular land use/land cover pattern for a given region over a specific time period (Wang et al., 2017).

$$P1 = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%, \tag{1}$$

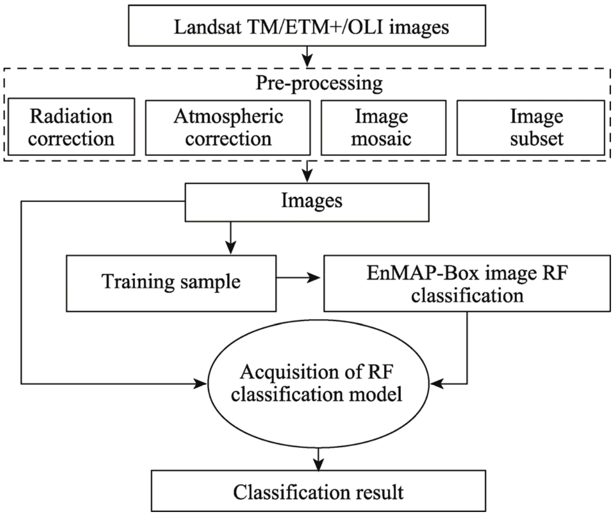

Fig. 3 Flowchart of the methodology used in this study. RF, random forest.

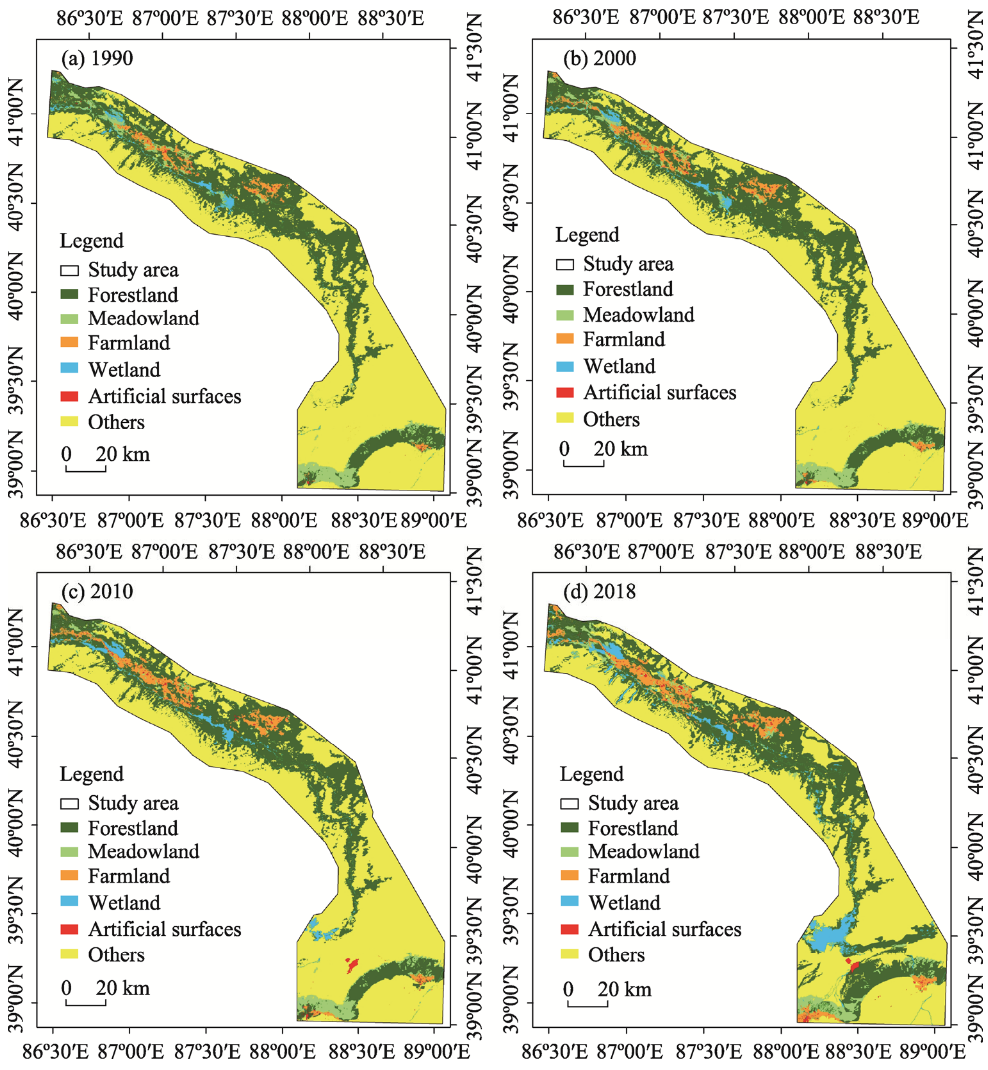

Fig. 4 Distribution of land use/land cover classification in the lower reaches of the Tarim River in 1990 (a), 2000 (b), 2010 (c), and 2018 (d)

where U_a and U_b represent the quantities of a particular land use/land cover pattern in the early and late stages of the research period in the study area (km^2), respectively; and T denotes the timespan (a).

3.3.2 Spatial variability of a single land use pattern ($P2$)

The spatial variability of a single land use pattern ($P2$) was introduced because $P1$ only reflects the quantitative change of land use/land cover patterns but not the degree of spatial change that has occurred. The $P2$ (%) value can reveal the dynamic degree of spatial change in specific land use/land cover pattern to some extent (Wang et al., 2017).

$$P2 = \frac{\Delta U_{in} + \Delta U_{out}}{U_a} \times \frac{1}{T} \times 100\% , \tag{2}$$

where ΔU_{in} and ΔU_{out} represent the areas transferred into and out of a land use/land cover type (km^2), respectively, during the study period.

4 Results

4.1 Spatial distribution of LUCC

Distribution of land use/land cover patterns in the lower reaches of the Tarim River in 1990, 2000, 2010, and 2018 (Fig. 4) can be used to analyze LUCC in the study area for the 29-a study period.

To explore the changes in land use/land cover over the study period more accurately, we calculated a transition matrix for the LUCC in the study area for 1990 and 2018 (Table 1). As shown in Table 1, LUCC varied significantly over the study period, and the area of LUCC was 2644.34 km^2, accounting for 15.79% of the total area (16,761.03 km^2).

Table 1 Land use/land cover change (LUCC) matrix in the lower reaches of the Tarim River in 1990 and 2018 (km^2)

	Meadowland	Farmland	Forestland	Others	Artificial surfaces	Wetland	Total in 1990
Meadowland	338.62	154.57	126.63	26.87	11.55	63.89	722.14
Farmland	7.30	321.66	18.80	0.25	10.09	3.11	361.20
Forest land	202.89	284.00	4026.31	252.27	9.31	243.72	5018.50
Others	64.58	29.17	1046.52	8864.39	36.75	331.25	10,372.67
Artificial surfaces	0.78	7.41	1.21	0.72	16.11	0.15	26.39
Wetland	4.63	11.07	83.58	9.34	0.09	137.37	246.08
Total in 2018	618.80	807.88	5303.06	9153.84	83.90	779.50	16,746.98
Change in area	–103.34	446.68	284.55	–1218.83	57.51	533.42	0.00
Change in area rate (%)	–14.31	123.66	5.67	–11.75	217.96	216.77	0.00

Forestland covered the largest land area in 2018 (5303.06 km^2), indicating an increase of 284.55 km^2 (5.67%) compared to 1990. The area of meadowland was largest in 1990 (722.14 km^2) and smallest in 2010 (493.09 km^2). The meadowland area decreased by 103.34 km^2 (14.31%) between 1990 and 2018, while the farmland area increased continuously, covering 361.20, 517.11, 690.67, and 807.88 km^2 in 1990, 2000, 2010, and 2018, respectively, showing a total increase of 446.68 km^2 or 123.66%. Wetland area exhibited the greatest increase of 533.42 km^2 (216.77%), more than twice its size, from 1990 to 2018. Artificial surfaces area also increased from 26.39 km^2 in 1990 to 83.90 km^2 in 2018, demonstrating an increase rate of 217.96% (57.51 km^2). Compared with 1990, the area covered by other land use/land cover types (such as Gobi, bare soil, and deserts) decreased by 1218.83 km^2 or approximately 11.75% in 2018.

In order to make a clearer statistic of the area, location, and trend changes of LUCC, we conducted a superposition analysis of the land use/land cover classification maps of 1990 and 2018 to obtain the LUCC map of the study area during the study period (Fig. 5). Artificial surface, such as mining fields and construction and transportation lands, expanded rapidly by

217.96% from 1990 to 2018, which was primarily converted from meadowland (13.77%), forestland (8.54%), farmland (12.02%), and wetland (0.10%). From 1990 to 2018, the area covered by wetland increased by 533.42 km^2 (216.77%), which was mainly converted from other land use/land cover types (42.50%), forestland (31.27%), and meadowland (8.20%). The amount of farmland in the study area increased by 446.68 km^2 (123.66%) from 1990 to 2018, mainly replacing forestland (35.15%) and meadowland (19.13%). Additionally, the area covered by certain land use/land cover types was reduced during this period. Specifically, meadowland was primarily replaced by farmland (19.13%) and artificial surfaces (13.77%), and parts of Gobi, bare soil, and deserts were mainly converted to artificial surfaces (43.80%) and farmland (42.50%). By the end of the study period (2018), artificial surfaces did not occupy a particularly large proportion of the study area, but the growth rate of this land use/land cover was high, increasing from 26.39 km^2 in 1990 to 83.90 km^2 in 2018 (217.92%).

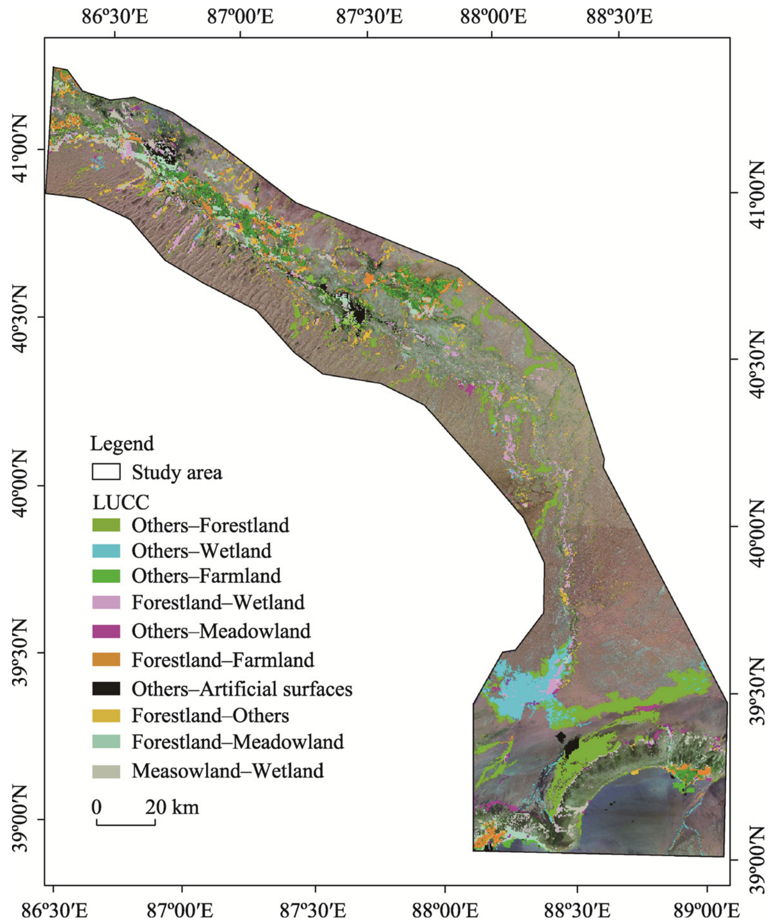

Fig. 5 Land use/land cover change (LUCC) in the lower reaches of the Tarim River from 1990 to 2018. "–" means the conversion of land use/land cover type.

4.2 Land use dynamic indices

Table 2 presents the *P*1 and *P*2 values for the periods of 1990–2000, 2000–2010, and 2010–2018. The *P*1 values for both meadowland and forestland in the first two decades (1990–2000 and 2000–2010) were negative, indicating a decrease in their area during these periods. In particular, the *P*1 of meadowland declined sharply, reaching a minimum of –2.63% during 2000–2010. The *P*1 values for meadowland and forestland were 2.66% and 0.98% during the periods of 2010–2018, respectively, indicating a positive trend. The total increase of *P*1 in meadowland and forestland was 5.29% and 1.11%, from 2000 to 2018, respectively, indicating their rapid growth

over the past years. The area of farmland increased over all three decades, as indicated by the positive $P1$ values. The area of wetland decreased from 1990 to 2000 (with $P1$ of –1.06%); however, it increased during the second and third decades, with comparatively higher $P1$ values of 6.71% and 11.36%, respectively. This rapid and substantial growth has coincided with the increase in water supply and drinking water facilities. The $P1$ values for artificial surfaces were also positive during 2000–2010 (12.54%) and 2010–2018 (0.84%). The area covered by artificial surfaces changed more significantly during the period of 2000–2010; however, the magnitude of this change decreased significantly after 2010. Since 2000, other land use/land cover types such as Gobi, bare soil, and deserts have exhibited successive decreases in $P1$ values (–0.12% and –0.98% for 2000–2010 and 2010–2018, respectively), indicating that the area of these land use/land cover types has declined steadily.

Table 2 Single land use dynamic index ($P1$) and spatial variability of a single land use pattern ($P2$)in the lower reaches of the Tarim River from 1990 to 2018

Land use/land cover type	1990–2000		2000–2010		2010–2018	
	$P1$ (%)	$P2$ (%)	$P1$ (%)	$P2$ (%)	$P1$ (%)	$P2$ (%)
Forestland	–0.17	0.32	–0.13	0.39	0.98	4.35
Meadowland	–0.74	1.03	–2.63	2.67	2.66	9.30
Farmland	4.31	4.31	3.36	3.79	1.79	4.73
Wetland	–1.06	3.11	6.71	7.42	11.36	17.31
Artificial surfaces	3.14	3.14	12.54	12.63	0.84	8.00
Others	0.00	0.00	–0.12	0.12	–0.98	1.65

The $P2$ values show that the area of meadowland and forestland generally increased from 1990 to 2018, although there have been periods during which the trend has varied significantly. The $P2$ values of meadowland and forestland during 2010–2018 were 9.30% and 4.35%, respectively, indicating that the spatial dynamics of these land use/land cover types changed significantly in 2009, and a large number of land use/land cover conversion occurred in the second half of 2009. This resulted in large $P2$ values from 2010 to 2018. The $P2$ values for farmland exhibited the smallest changes over the three target periods (4.31%, 3.79%, and 4.73%, respectively), implying a steady conversion of farmland. The $P2$ values for wetland demonstrated an increasing trend over the three target periods (3.11%, 7.42%, and 17.31%, respectively), with the largest value observed in 2010–2018. The $P2$ value of artificial surfaces was higher during 2000–2010 and lower during 2010–2018, suggesting a relatively large impact of spatial disturbances.

5 Discussion

5.1 Trends of LUCC

The following three aspects are required to effectively utilize remote sensing data to analyze LUCC: location, direction, and process (Hasselmann et al., 2010; Jiang et al., 2015). Understanding the locations where changes occur is vital for ecosystem monitoring and can help to analyze and explain the causes of such changes (Huang et al., 2006; Chen et al., 2008). Analyzing LUCC in response to ecological and environmental changes and human intervention is useful for understanding the trend of LUCC (Li et al., 2017; El-Tantawi et al., 2019). In this study, LUCC in the lower reaches of the Tarim River was analyzed using images captured by satellite remote sensing in 1990, 2000, 2010, and 2018. The superposition of land use/land cover classification maps from 1990 to 2018 can facilitate a better understanding of the changes, locations, and trends in land use/land cover.

The results indicate that there was a large amount of farmland developed near the Qiala Reservoir during the study period. Most of forestland that extended outwards from both sides of the river toward the desert and Gobi has become wetland, indicating that the water-receiving area of vegetation has expanded on both sides of the river (Ye et al., 2010; Keyimu et al., 2017). In

1990, most of meadowland around the Daxihaizi Reservoir was converted to forestland and a small part to wetland by 2018. The small river course downstream of the Daxihaizi Reservoir has widened significantly, resulting in a large river course with large puddles and pits in many locations. The farmland area around the Tikanlik Town (40°37′47.53″N, 87°41′23.91″E) in Ruoqiang County of Bayingol Mongolian Autonomous Prefecture in Xinjiang increased significantly, forming contiguous tracts. Notably, the Taitema Lake, located in the lower reaches of the Tarim River, had no water in 1990 and 2000. From 2010 to 2018, the amount of water increased, making it the second largest lake in southern Xinjiang. Most of the surrounding environment was simultaneously improved and restored, and the area of forestland on both sides of the river has increased by 284.55 km^2 (5.67%), mainly in the parts of river overflow and stagnant pools. This suggests that river overflow promoted the recovery of local vegetation and the formation of fragmented and irregular forestland.

5.2 LUCC responses to ecological water conveyance

To clearly understand the LUCC in the lower reaches of the Tarim River, we analyzed the area of wetland and vegetation (including forestland and meadowland) during the period from 1990 to 2018. The wetland area changed as follows: 2000<1990<2010<2018 (Fig. 6); specifically, it was similar between 1990 and 2000, and increased from 368.08 km^2 in 2010 to the maximum of 786.10 km^2 in 2018. The cumulative water conveyance days of the 11th water conveyance project from June to November in 2010 was 139 d, i.e., the total volume of 3.89×10^8 m^3 (Fig. 1). In 2018, there were two water conveyance periods: February and August (Wu and Cai, 2004; Ablekim et al., 2016). The cumulative water conveyance days were 88 d, and the cumulative water conveyance volume was 4.29×10^8 m^3, an increase of 0.39×10^8 m^3 compared with 2010. It can be seen that wetland has been greatly improved.

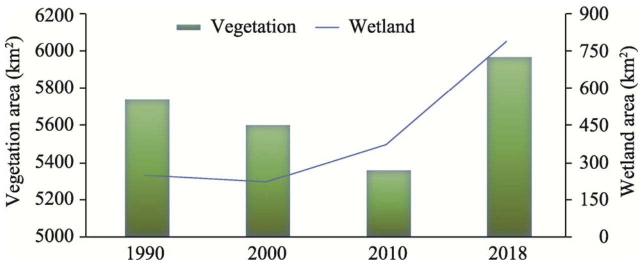

Fig. 6 Annual changes in the area of vegetation and wetland in 1990, 2000, 2010, and 2018

The change in vegetation area followed the trend of 2010<2000<1990<2018, as shown in Figure 6. Vegetation area decreased by 138.20 km^2 between 1990 and 2000 and 241.81 km^2 between 2000 and 2010; however, it recovered between 2010 and 2018, increasing by 609.21 km^2. This indicates that vegetation has undergone a process of degradation and then restoration. Many studies have suggested that the benefits of water conveyance will take several years to be visible and cannot be observed immediately (Wan, 2012; Guo et al., 2017; Wang and Guo, 2018). Similar to the gradual degradation of vegetation before water conveyance, the ecological responses of downstream vegetation and groundwater are also slow on the spatio-temporal scale (Chen et al., 2015a, b; Keyimu et al., 2017). For example, we analyzed the relationship between vegetation area in 2010 and 2018 and ecological water conveyance in previous years (2009 and 2017, respectively). In December 2009, the cumulative number of water conveyance days was 26 d, and the cumulative water conveyance capacity was 0.11×10^8 m^3, reaching the position of Kaerdayi. Water conveyance in 2017 was divided into three months: April, May, and December; there were 215 cumulative water conveyance days, and the cumulative amount of water delivery was 8.33×10^8 m^3. This affected the growth of vegetation in 2018. In addition, early ecological water conveyance was launched in February 2018 to solve the problem of ecological water supply in spring. The change in vegetation area in each year was positively correlated with the cumulative ecological water conveyance in the previous year, with one, two, three, four, and five

years of cumulative ecological water conveyance volume in response to LUCC. Therefore, the short-term and long-term effects of cumulative ecological water conveyance effectively promote the natural restoration of vegetation on both sides of the river (Ye et al., 2009; Zhang et al., 2013).

Variations in vegetation and wetland areas are influenced by multiple factors, including climate, the amount of water delivered, the number of water conveyance days, the time of water conveyance carried out, the average rate of water conveyance, and human factors (Lu and Jiang, 2009; Bai et al., 2015; Xu et al., 2015; Ling et al., 2019; Wang et al., 2020). Our study indicated that the main source of groundwater recharge in the lower reaches of the Tarim River is river runoff in both vertical and horizontal directions, and the amplitude of groundwater level fluctuations gradually slows down with increasing distance both vertically and horizontally (Wu and Cai, 2004; Yu et al., 2012; Li et al., 2017). Based on the interpretation of remote sensing images and field monitoring, it can be concluded that shallow groundwater level in the lower reaches of the Tarim River increased as a result of ecological water conveyance. According to the monitoring data, the depth of groundwater increased from 9.8–10.1 to 2.1–5.3 m at a distance of 1 km from the main river channel, and groundwater mineralization increased from 1.1–3.0 to 5.3–7.8 g/L during the period from 2000 to 2017 (Ablekim et al., 2016; Chen et al., 2019). Previous studies showed that vegetation in the lower reaches of the Tarim River has been restored, and the area increased to 2285.00 km^2, with an increase of 362.00 km^2. The sandy area decreased by 854.00 km^2 and the number of plant species increased from 17 to 46, with hogweed, white thorn, camel thorn, reed, sand jujube, and licorice as the main types (Fan et al., 2013, 2014; Ye et al., 2014a, b; Chen et al., 2015a, b, 2020). Some drought-tolerant trees and shrubs also gradually recovered, and the floral biodiversity gradually restored. After years of continuous ecological water conveyance, the flooded poplar forestland area in the lower reaches of the Tarim River reached a total area of 712.00 km^2. Extensive poplar forests that had died due to lack of water have been restored. Additionally, area of artificial surfaces exhibited an increasing trend, while area covered by other land use/land cover types, such as Gobi, bare soil, and deserts, decreased significantly, indicating that the study area was increasingly affected by human activities, mainly since 2000 (Hartmann et al., 2016; Bao et al., 2017; Huang et al., 2018). However, according to the response of LUCC to ecological water conveyance analyzed in this study, the increased area and the recovery of vegetation were still mainly concentrated in certain areas. Therefore, further efforts should be made to ensure long-term, stable, and more scientific ecological water conveyance and rational utilization of water resources in the lower reaches of the Tarim River.

This study explored the effects of ecological water conveyance in the lower reaches of Tarim River from the perspective of LUCC, but the effects are not limited to those. LUCC is a complex process that requires consideration of human activities and climate change (Chen et al., 2020; Li et al., 2021). This study only considers the impact of ecological water conveyance on LUCC, but the climate change factors such as temperature and precipitation, as well as natural factors such as topography and soil organic matter content may also affect LUCC, which need to be studied in the future.

6 Conclusions

Based on multi-scene and multi-temporal remote sensing dynamic monitoring data, we investigated the response of LUCC to ecological water conveyance in the lower reaches of the Tarim River during the period of 1990–2018. The area of LUCC was 2644.34 km^2 during 1990–2018, accounting for 15.79% of the total area. During the study period, area of wetland, farmland, forestland, and artificial surfaces increased; while area of grassland and other types including Gobi, bare soil, and deserts decreased. Improved vegetation was concentrated on both sides of the river and was distributed in overflow and stagnant areas, indicating that river overflow promoted the restoration of local vegetation, especially the conversion of meadow to wetland and farmland. Long-term, intermittent, and stable artificial ecological water delivery is an important reason for the ecological and environmental changes in the lower reaches of the Tarim River.

Land use/land cover in the study area affects the regional natural environment, including

groundwater, microclimates, natural vegetation, and wildlife; it has a significant impact on human lifestyle and living standards. Using multi-scene and multi-temporal remote sensing dynamic information monitoring, this study provides guidance for the rational development and utilization of water and soil resources, and puts forward the development strategy of the Tarim River based on ecological security, serving as a scientific guideline for the optimal regulation of water resources and reasonable allocation of ecological water.

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